Cyclotrons2010
中国蘭州

Operating Experience with the RF System for the Superconducting Ring Cyclotron of RIKEN RIB-Factory

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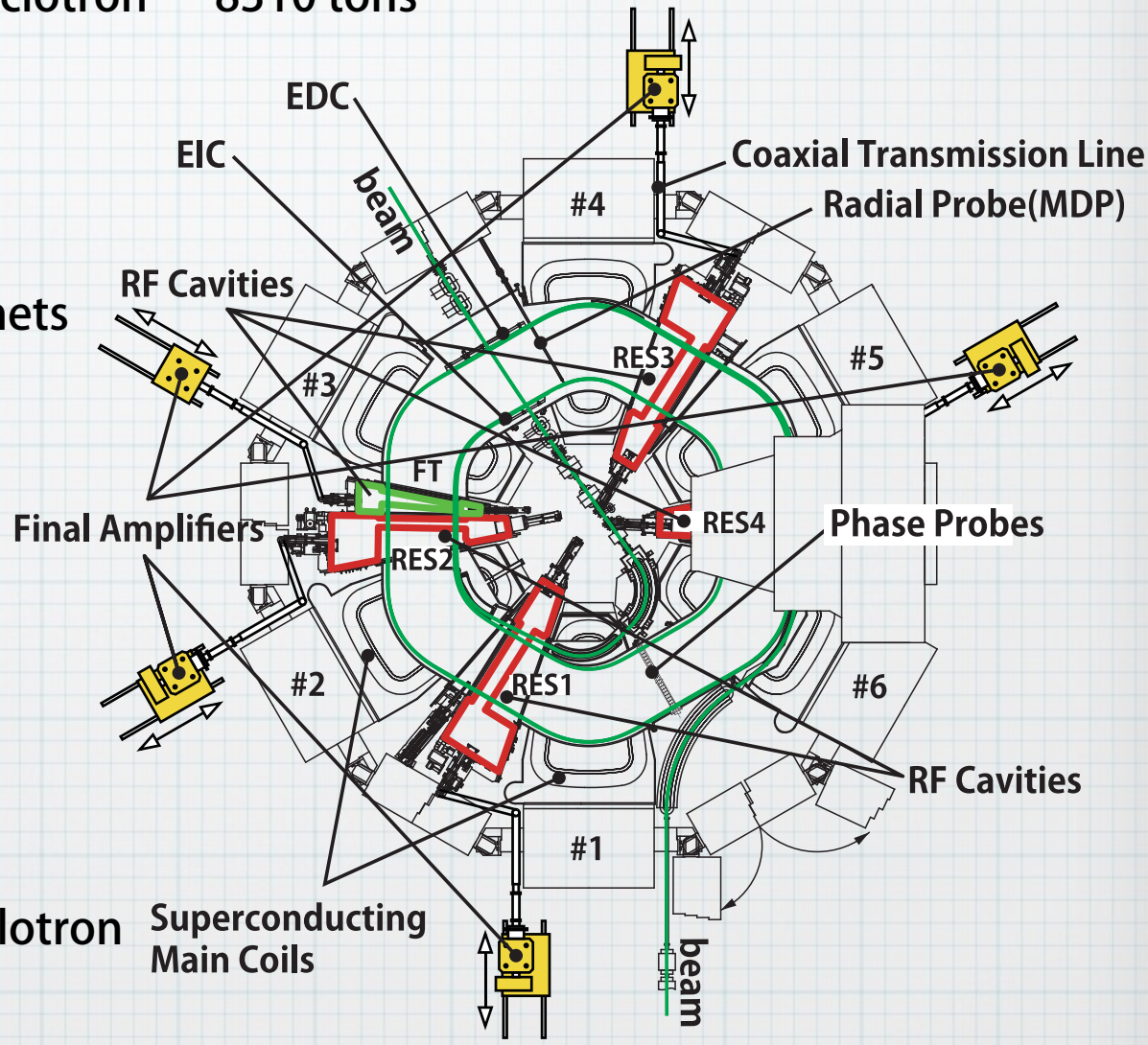
Nishina Center, RIKEN

RIKEN Superconducting Ring Cyclotron for RIB-Factory

- The heaviest Superconducting Cyclotron -8310 tons-
  - Operational since Dec. 2006
- Present performance
  - ^{238}U/345 MeV/nucleon 0.8 pnA
  - ^{48}Ca/345 MeV/nucleon 230 pnA
- Six Superconducting Sector Magnets
  - K2.6GeV Bmax= 4.2 T with 5000 A
  - ^{238}U/345 MeV/nucleon (36.5 MHz H6)
  - Stray Field at Valley Bv～a few kG.
- Four Acceleration Cavities
  - Vg = 2 MV/turn @ 36.5 MHz
  - Single Gap Cavity Vmax 550 kV
- Flattop
  - The third harmonic cavity -240 kV
  - Large longitudinal Acceptance
- Beam probes for Isochronous Cyclotron
  - PP: Phase Probe
  - MDP: Main and Differential Probes



Topics

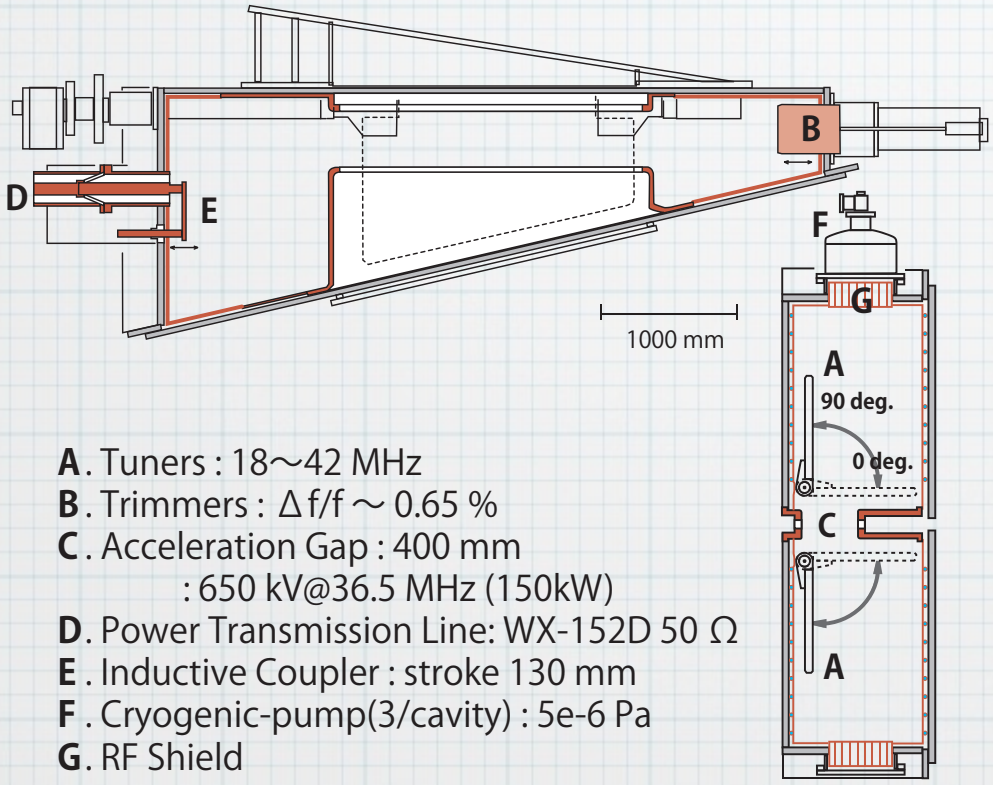
- RF System for the SRC -what we made, how we operate-
  - Cavities
  - Amplifier
  - Control of Parasitic Oscillation
  - Present Performance
- Operating Experiences -problems-
  - RF Power Leakage
  - Countermeasure against rf noise for beam probes
  - Multipactor

Cavities

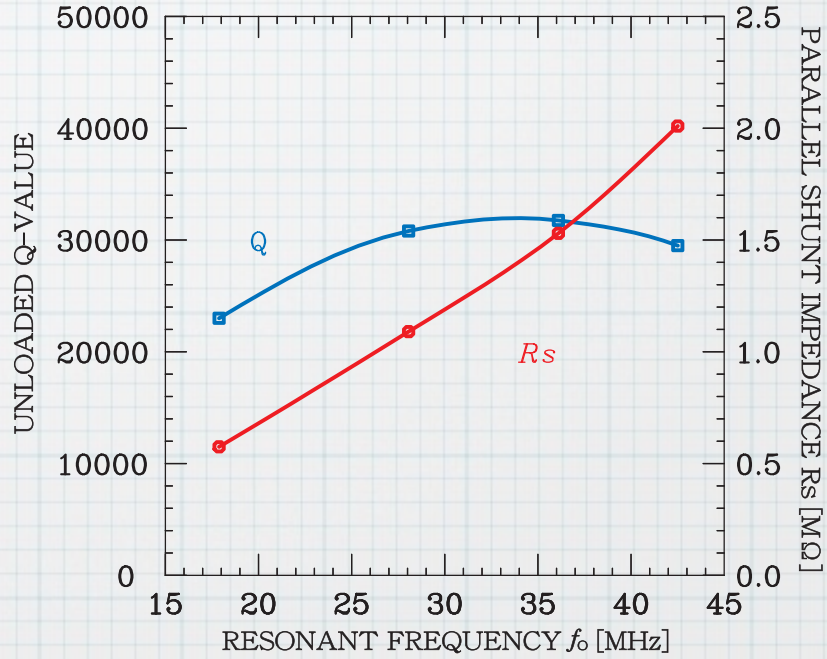
- **Single gap cavity with a pair of capacitive tuner**

18～42 MHz, Qo= 20000～30000, Rs = 1.1～1.6 MΩ

[Design: RIKEN, Construction:SHI/Japan]



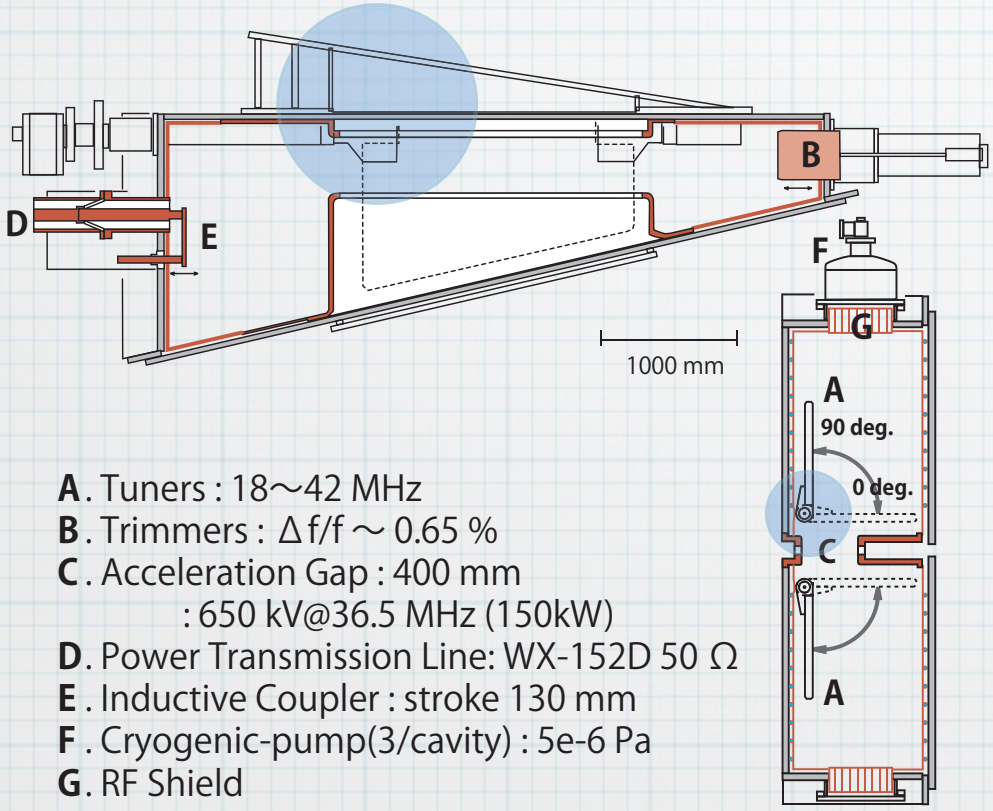
A. Tuners : 18～42 MHz
B. Trimmers : Δf/f ～ 0.65 %
C. Acceleration Gap : 400 mm
: 650 kV@36.5 MHz (150kW)
D. Power Transmission Line: WX-152D 50 Ω
E. Inductive Coupler : stroke 130 mm
F. Cryogenic-pump(3/cavity) : 5e-6 Pa
G. RF Shield



In the initial stage the voltage is restricted to 450 kV

Cavities - sliding contacts-

- Sliding contacts got damaged with 100 kW RF Power



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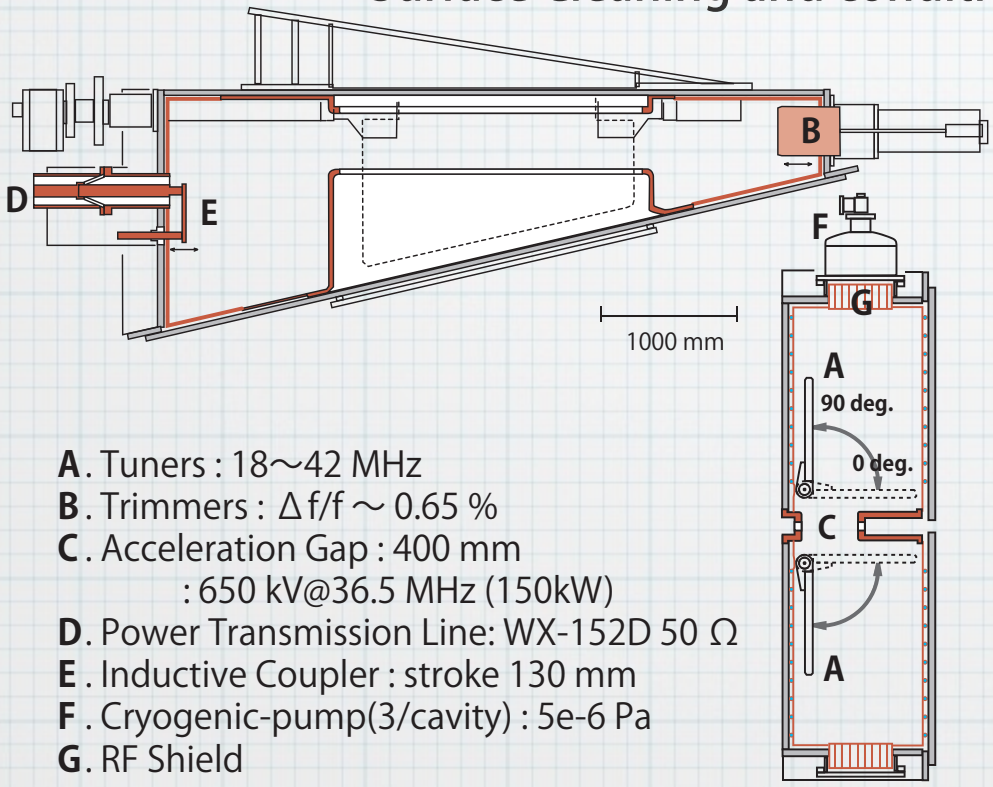
Modification of the shape of the contact finger

Cavities -vacuum-

- Serious discharge was observed at about 500 kV
- The vacuum pressure with rf power is about 1×10^{-4} Pa

Surface Cleaning and conditioning with low power



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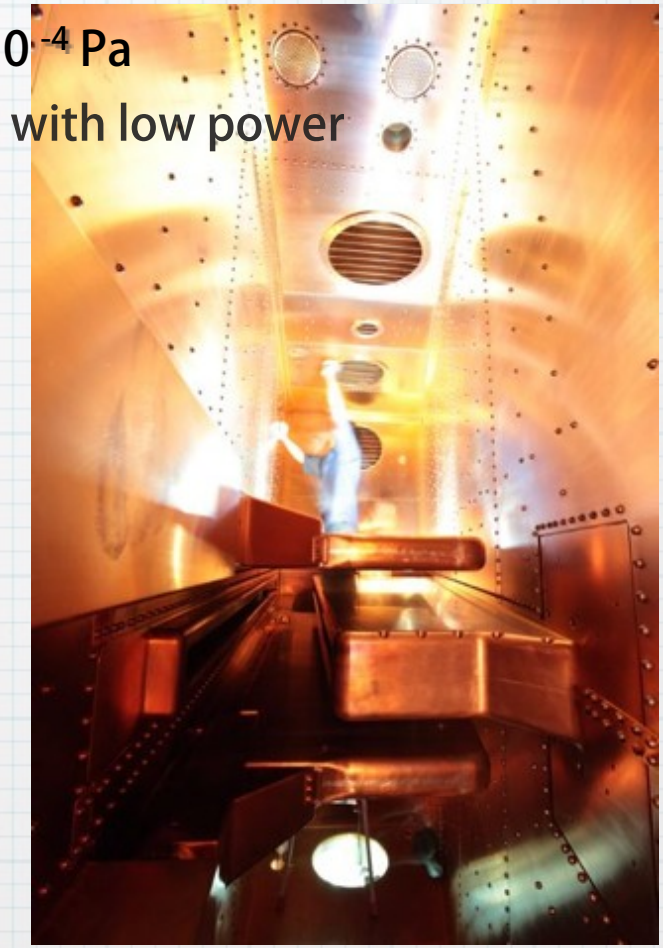
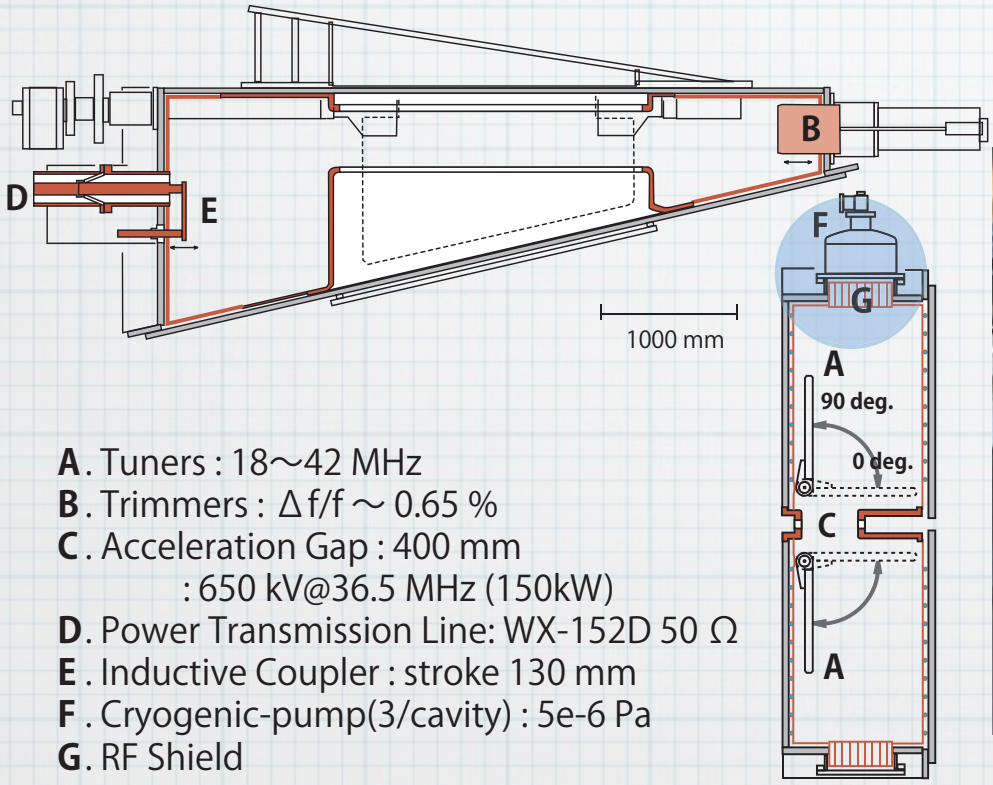


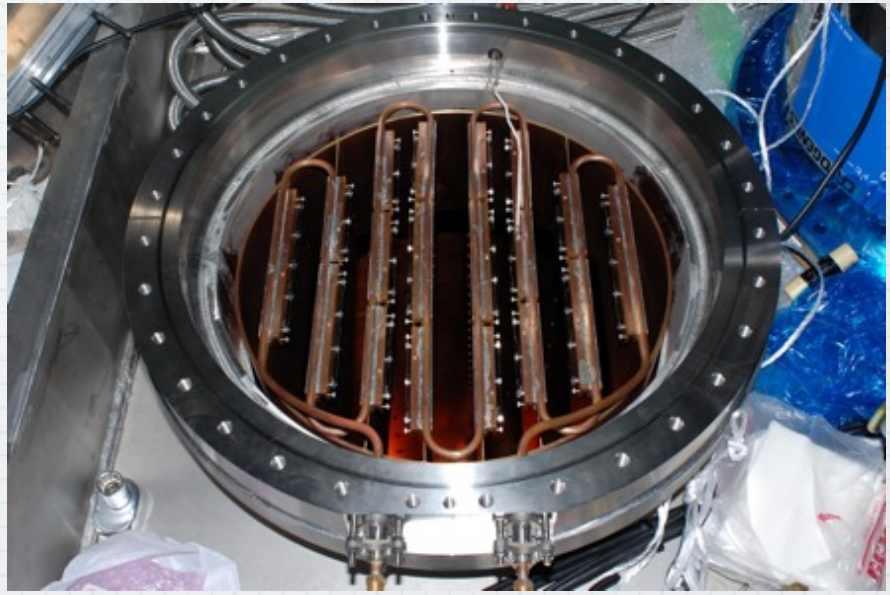
Vacuum pressure has been improved 5×10-6 Pa

Cavities - cooling-

- Temperature rise of cryogenic panels

Cooling of the RF shield was not enough against rf heating





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Cooling channel has been introduced to the RF shield

Amplifier

- Tetrode based grounded-grid amplifier
  RS2042SK coupled w/ RS2012 CJ
- Power Output 150 kW
- Frequency tunable 18～42 MHz
- Stray field of the sector magnet ～100 G
  Dummy load test w/ stray field
- Parasitic mode

input STUB	55 MHz
G1-G2	98 MHz

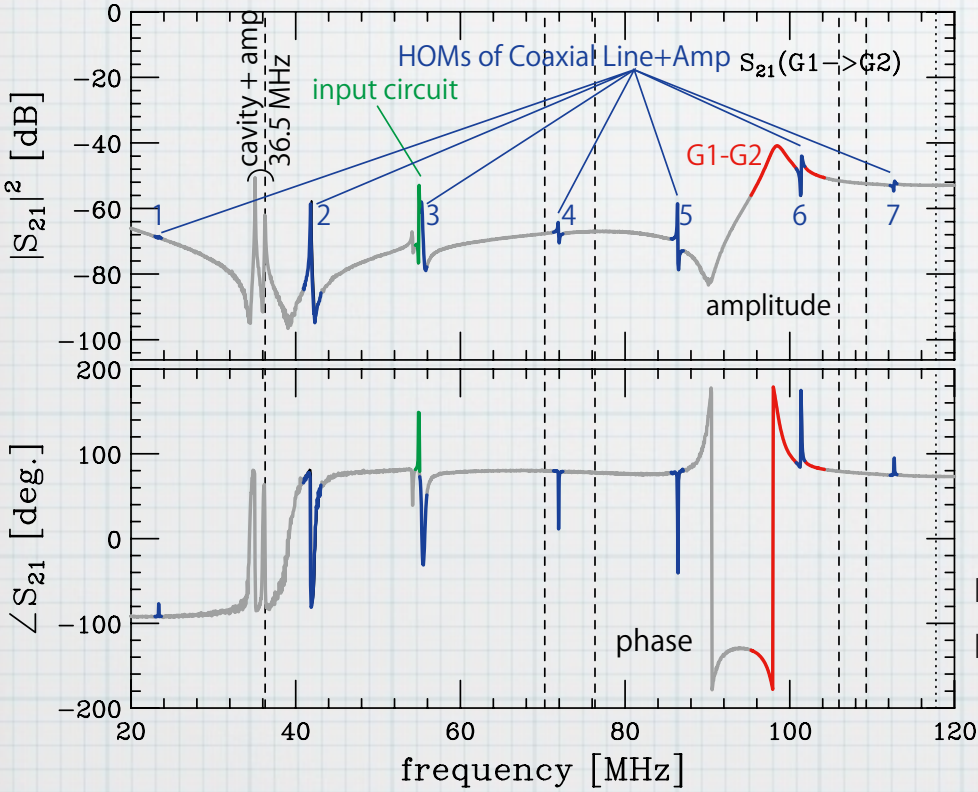
THALES RS0242SK

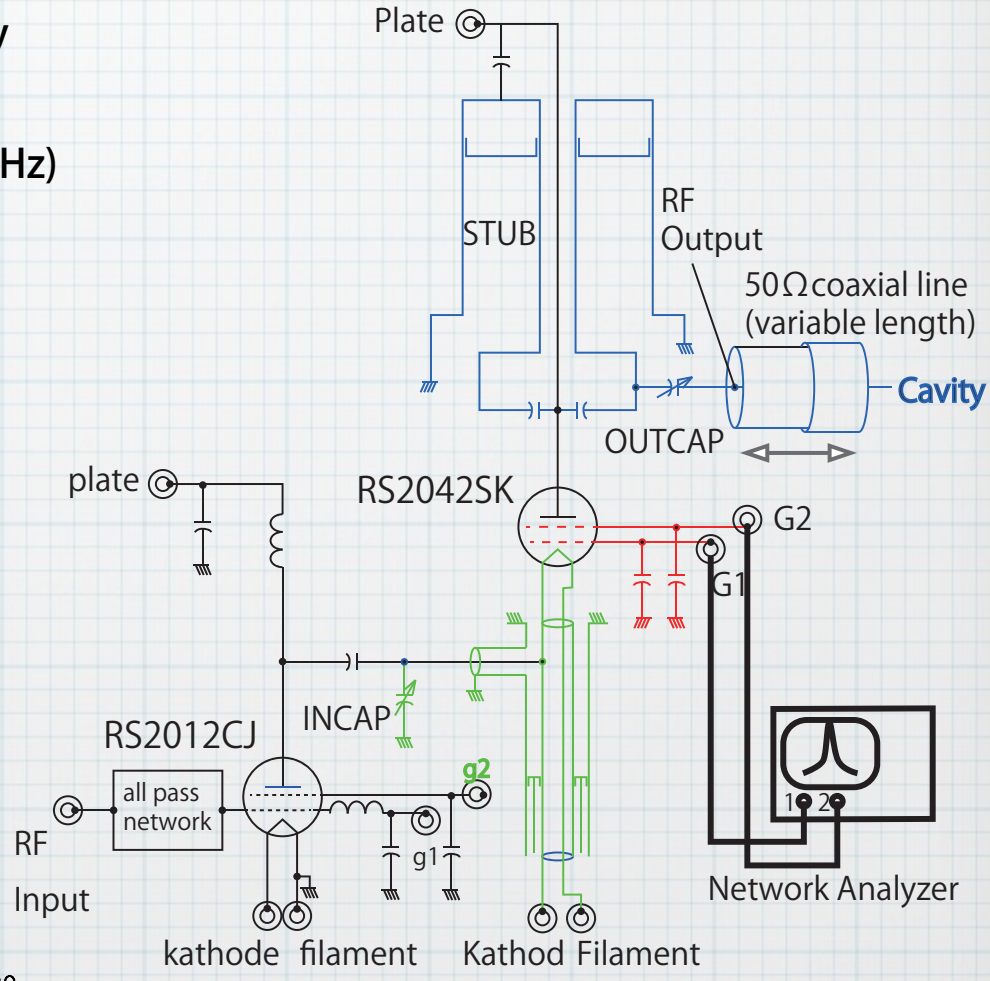
Parasitic modes measurement S_{21}(G1→G2)

- HOMs of the cavity (dashed line) do not couple with amplifier.
- HOMs of Coaxial Line+Amp. :Blue
  - shorter the length →higher the frequency
- They must be separated from

  Green: the resonance of input circuit (55 MHz)

  Red:G1-G2 resonance (98.5 MHz)





The position shorter by 50 cm was chosen.

Performance of the RF System of the SRC

	Acceleration	Flattop
Frequency [MHz]	36.5	109.5
Number of cavities	4	1
Rs [MΩ]	1.5	1.65
Unloaded Q	30000	29000
Voltage [kV/cavity]	550	-240
$P_{w.l.}$ [kW/cavity]	100	18
Vacuum [Pa]	3×10^{-6}	1×10^{-5}
Voltage Stability	±0.03%	±0.03%
Phase Stability	±0.03°	±0.09°
Availability*	92%	99%

* Here availability is defined as all of the cavities are excited. Tuning time after failure/Scheduled conditioning excluded.

Acceleration voltage 2 MV/turn has been achieved

Topics

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  - Present Performance
- Operating Experiences
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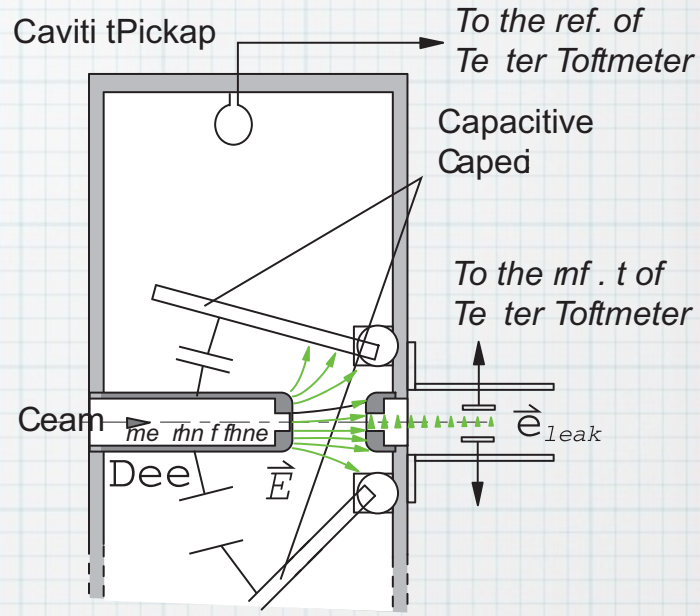
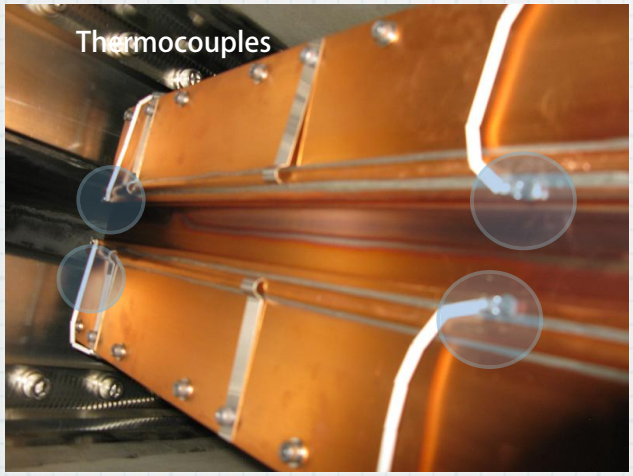
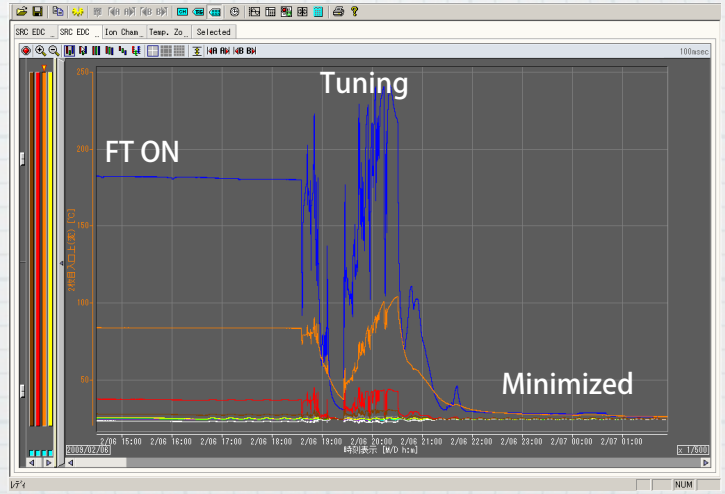
RF Leakage through the beam aperture

- Asymmetrical excitation causes rf power leakage through beam aperture
- Large noise to the beam probes (MDP,PP)
- Balance the field by adjusting tuners using :
  the rf power monitor outside the cavity and/or
  the thermocouples installed on Septum Electrode.





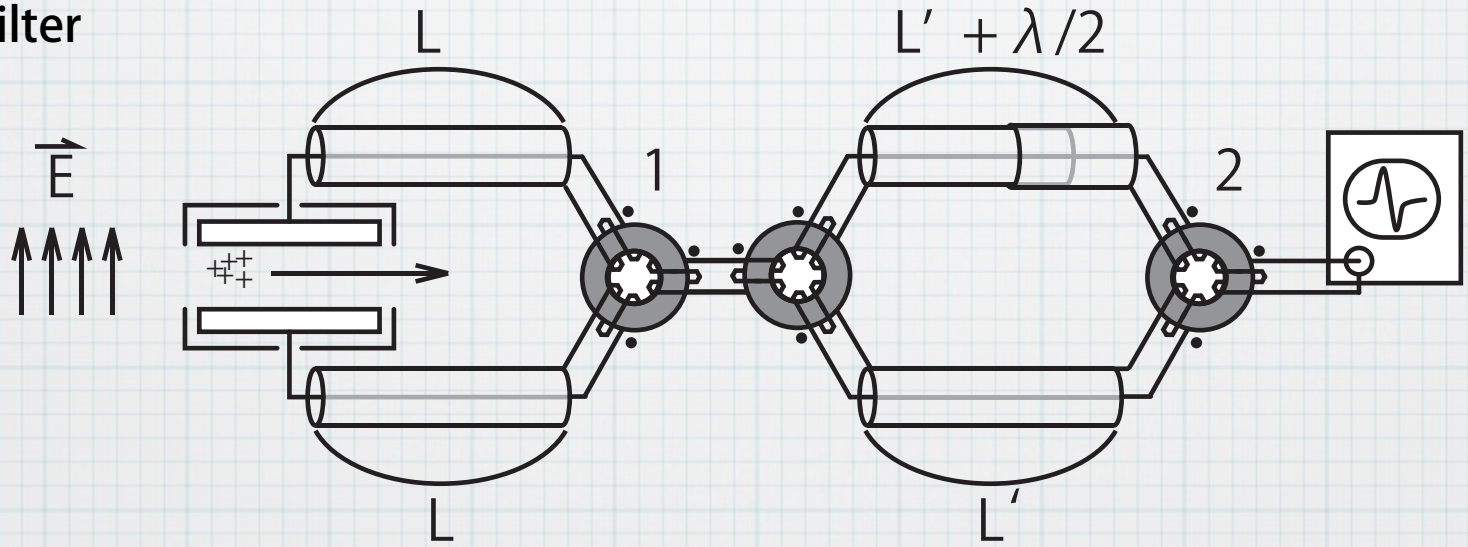


Filter against RF noise of -Phase Probe-

- 2f component of the beam signal is used to zero cross timing is obtained.

  S/N is large

- Vertical rf field brings dipole component to PP electrodes.
- Coaxial cables with combiner work as filter against these components.
- Odd harmonic rf components from FT and/or amplifier by the interferernce filter



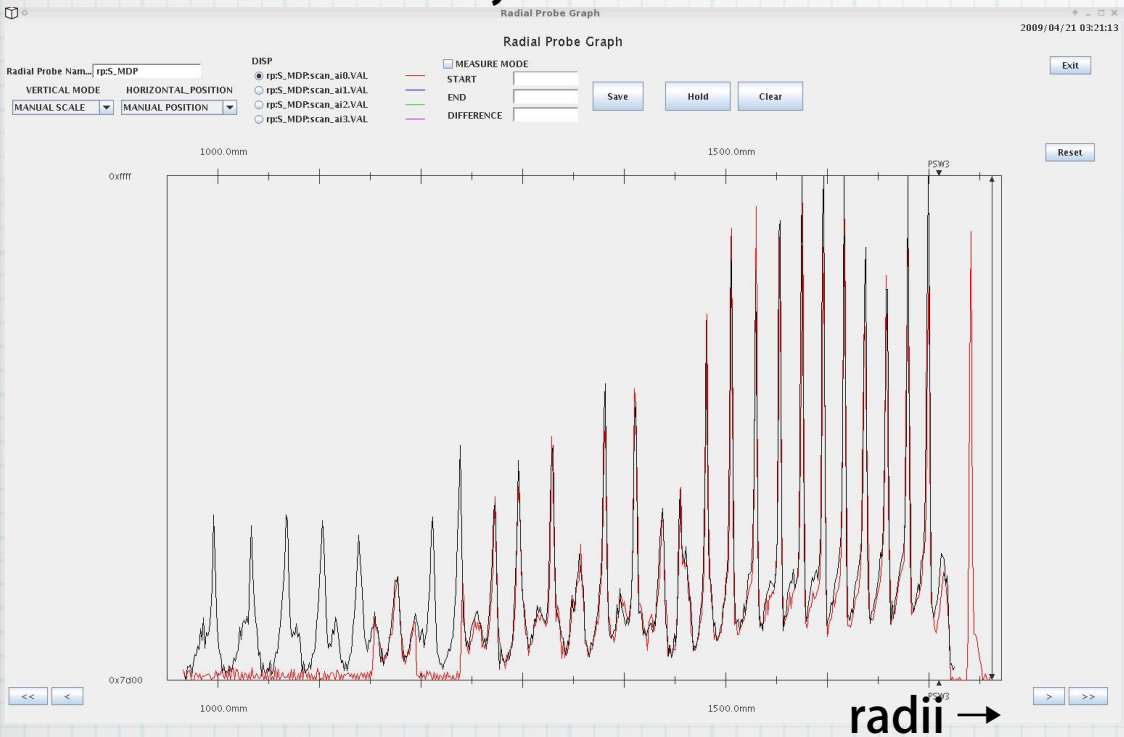
1 : cancel dipole component

2 : cancel odd harmonic component

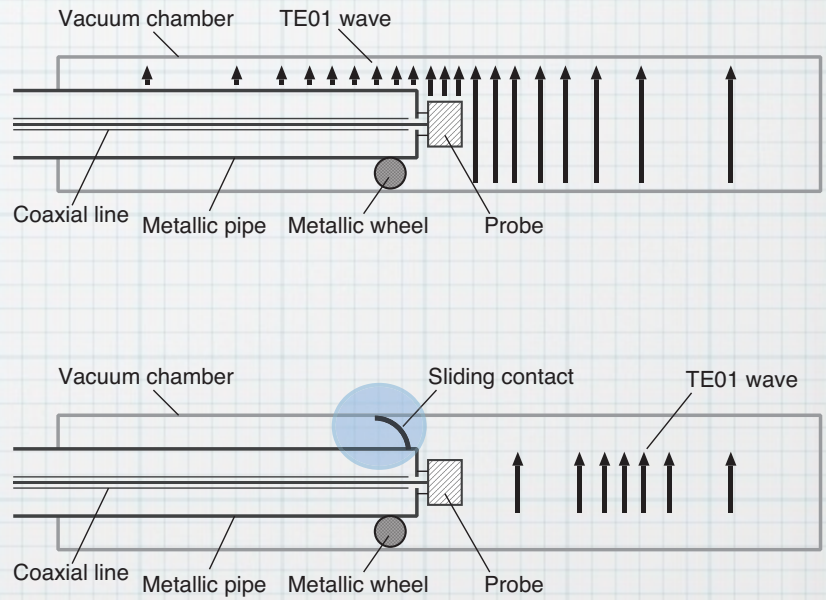
Suppression of TE01 mode of the MDP

- Noise depends on the position of the probe electrode

Beam Density Distribution



MDP



Additional contact onto the tip of the chassis successfully suppresses TE01 wave.

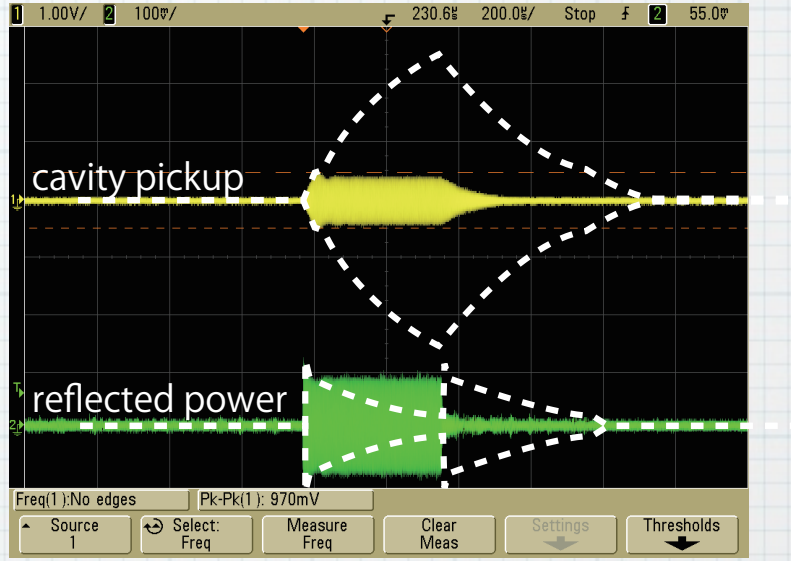
Multipactor

- Pulse Excitation

  -To overcome the multipactor rectangler pulse excitation is effective.

  -The situation of the multipacotor is strongly affected by the strength of the stray field.

  -Many levels are observed.



Expecting the situation of multipactor becomes moderate:

- Surface cleaning
- Long term conditioning with pulse rf power
- 10000 l/s Cryogenic Pumps 3 →4

Improvement of Conditioning Time at Cold Start

Pulse mode conditioning

Reputation 100 Hz,
Duty 1 %,
Peak Power 120 kW
Increasing the main coil current step by step
Conditioning time for Uranium 345 MeV/u
Jan. 2007： 3 weeks
June 2007： 1 week
Nov. 2007 : 2 days

CW mode conditioning

Duty 100%
Power 10～30 kW
Set the operation coil current first
Increasing the rf power step by step

Conditioning time for Uranium 345 MeV/u
Oct. 2008 ： 20 hours
Ca 345 Mev/u Nov. 2009 : 2-3 hours
After the cavities got wet in July 2009
Ca 345 Mev/u May. 2010 : 1-2 days

Recovery time when rf breakdown occurs : 3-4 hours was reduced to 5-30 minutes.

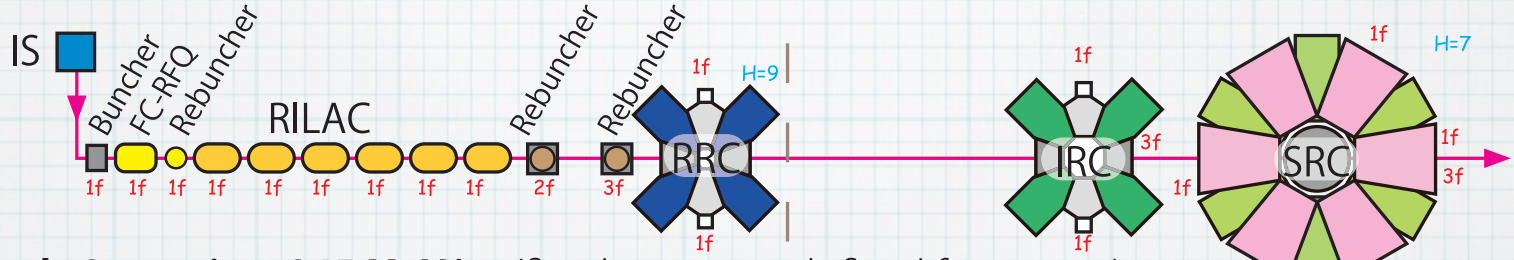
Summary

- By improving the vacuum, cooling, surface cleaning, the acceleration voltage of 2 MV/turn has been achieved.
- The beam probes, MDP, and PP work well after some modification.
- Multipactor is one of the most important issues which reduce the availability of the SRC.
- In order to minimize the break time due to the rf breakdown, cw power conditioning has been introduced. Recovery time was 5-30 minutes during the Ca experiment in May 2010.
- Conditioning at the cold start takes for 1 day.
- The availability of the rf cavities is more than 90% but still improvement of this number is required toward 99% which the IRC and the FRC have already achieved.

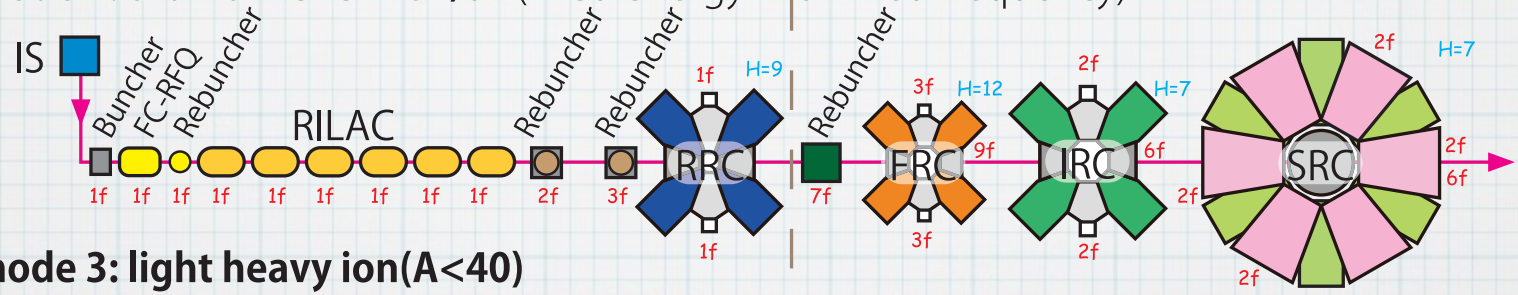
Thank you for your attention.

Accelerator Complex of RIKEN RIB-Factory

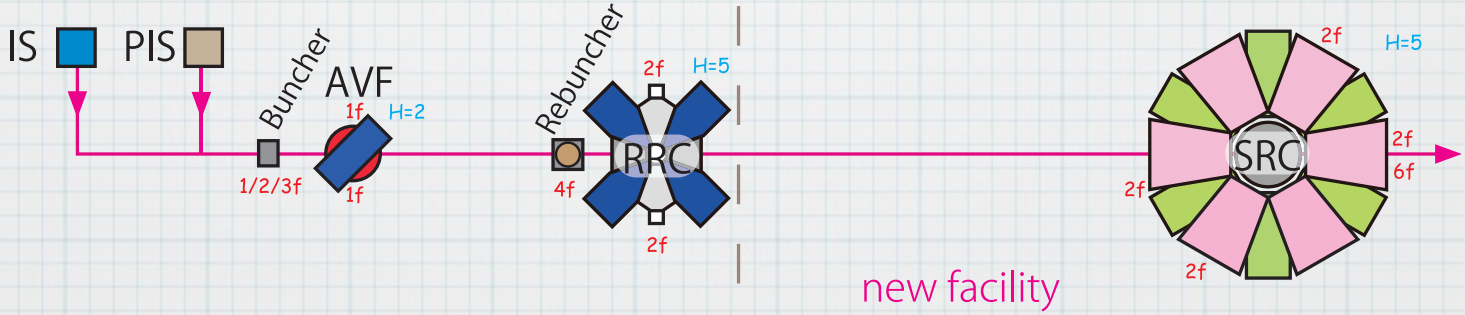
mode 1: very heavy ion(A>40) (variable energy with variable frequency)



mode 2: uranium 345 MeV/u (fixed energy with fixed frequency)



mode 3: light heavy ion(A<40)

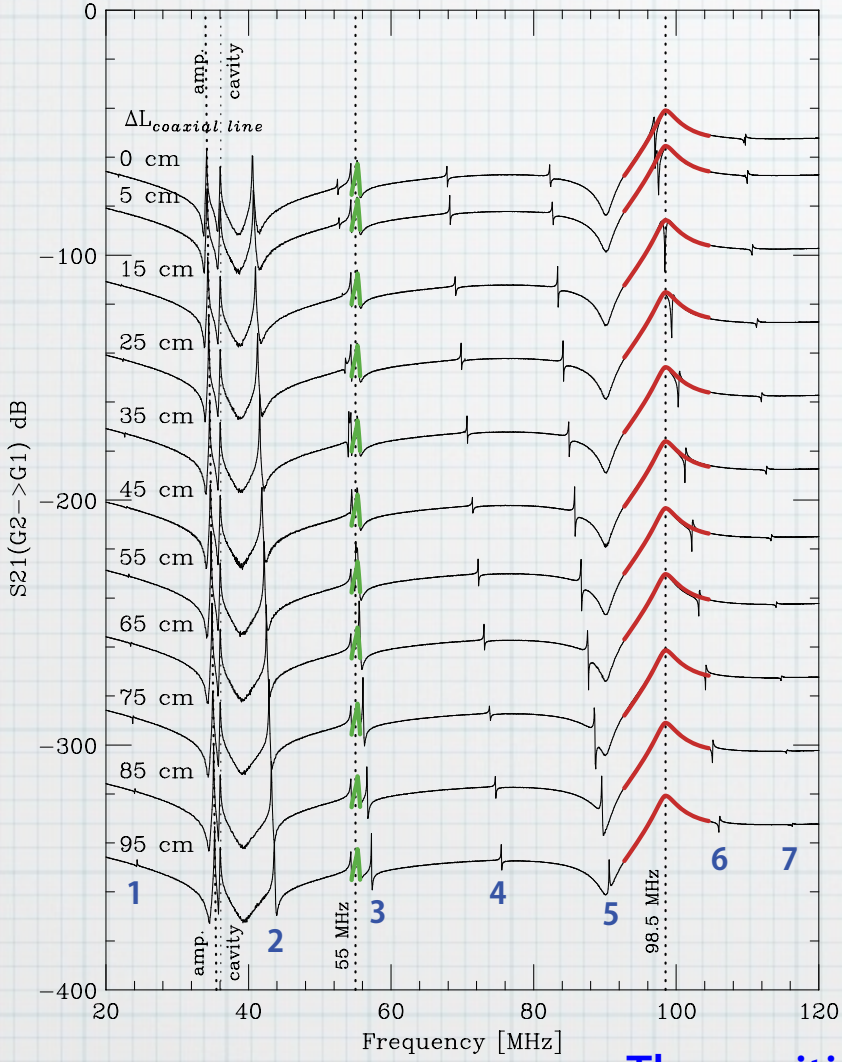


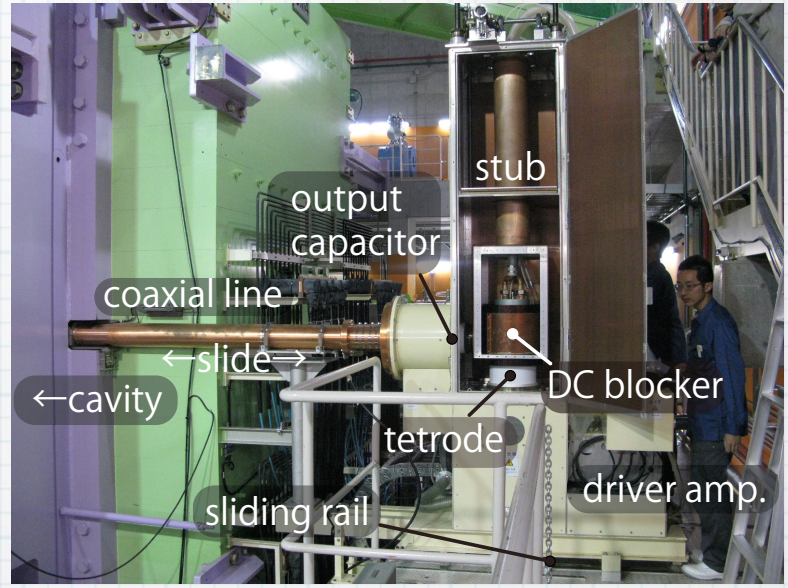
new facility

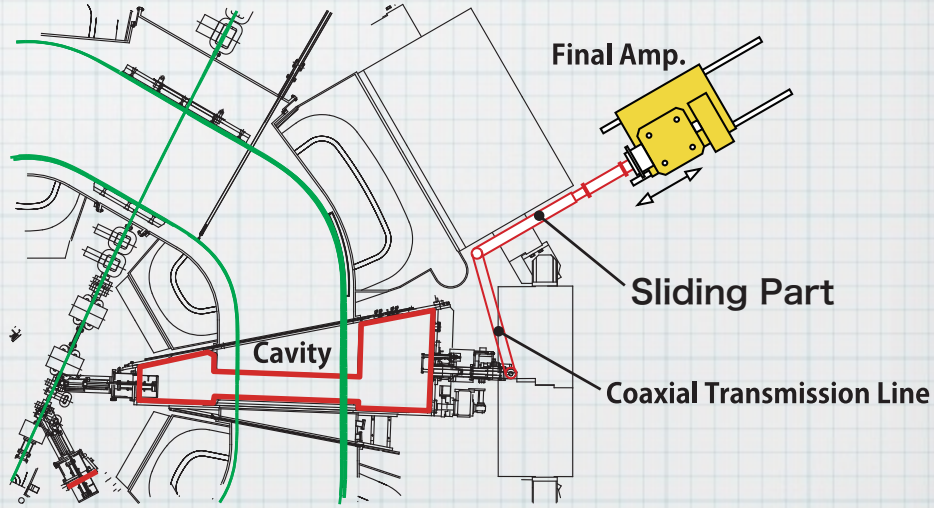
11 cavities for new cyclotrons

Variable Length Coaxial Line

- The coaxial length is variable with sliding part







The position of 95 cm was chosen.

Low Level Circuit - stability-

- Analog amplitude and phase feedback loop

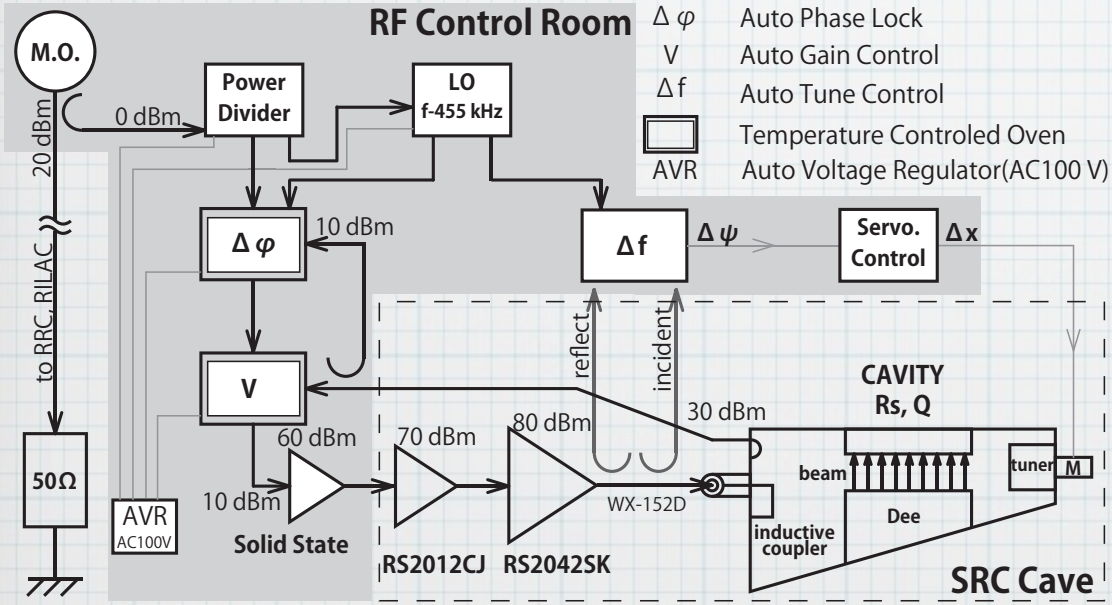
$|\Delta V/V| < 0.03\ \%, |\Delta\theta| < 0.03^{o}$

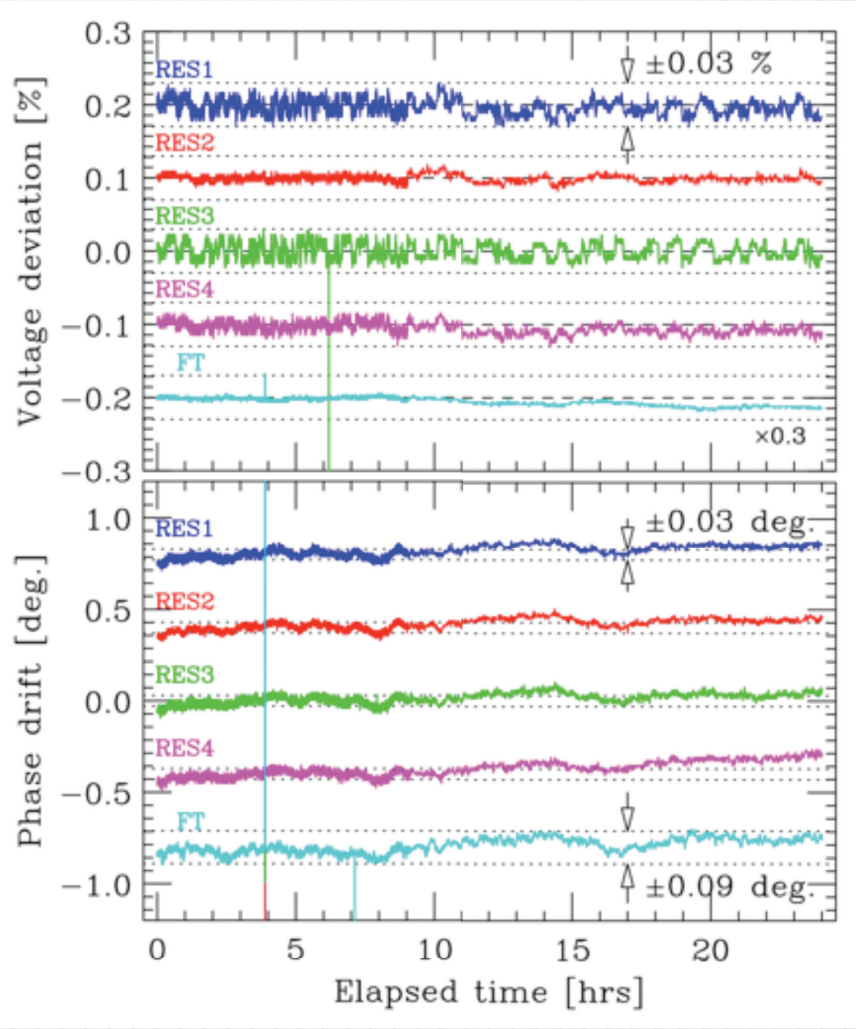
Thamway Corporation

- RF Monitor System utilizing

SR844 RF Lock-In-Amplifier

R. Koyama, EPAC08, Genoa(2008)p1173.



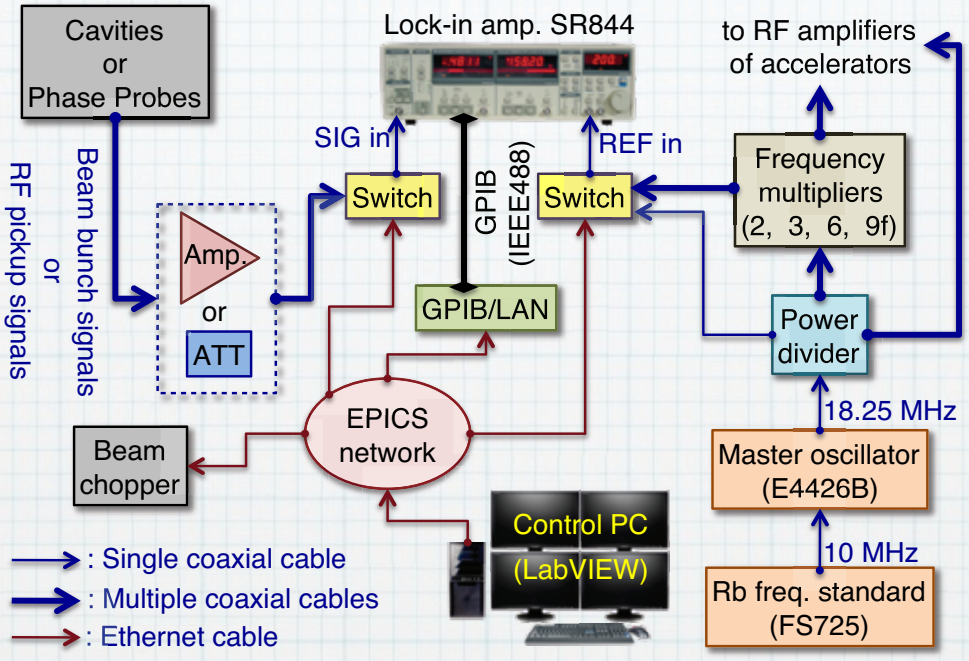


Monitoring System

- RF Lock-In-Amp. (Stanford Reserach Systems)

  wide bandwidth : 25 kHz - 200 MHz

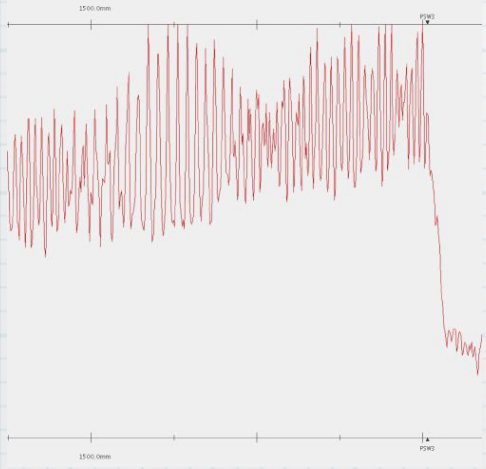
- Feasibility : OK
- amplitude : 10^{-4}, phase : 0.03^{o}
- Labview control



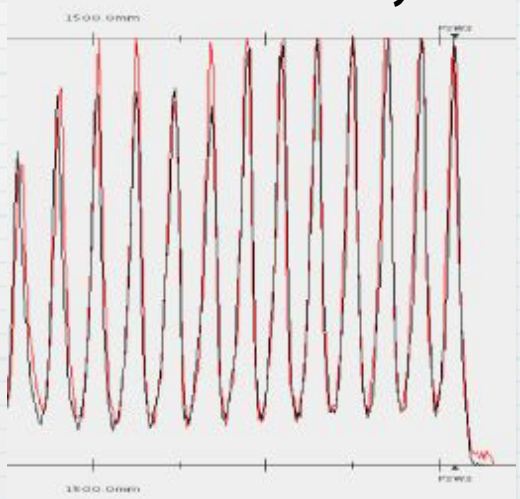
R.KoyamaM.Fujimaki

Flattop Acceleration for Single Turn Extraction

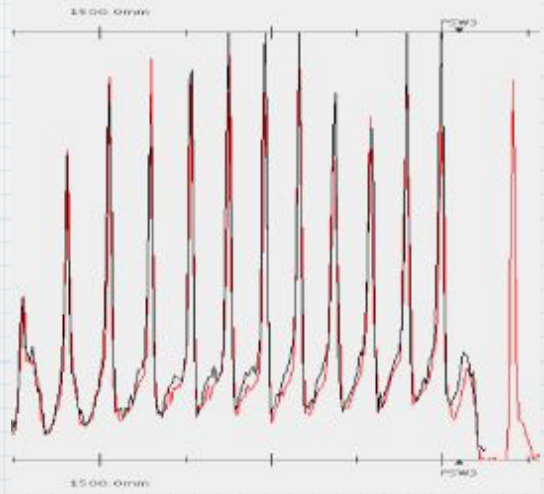
- Turn off the flattopping cavity
- Tune the phase of the acceleration cavity w/ well-centering
- make off-centering
- Tune the flattopping cavity to make the profile as sharp as possible
- 99.99% single-turn (Transmissionn effiency 50 %)



well-centered
EIC 70 kV



off-centering
EIC 48 kV



flattop on
single turn extraction!

Fast Recoery

- Pulse/CW mode via Multipactor
- Recovery within 1 ms
- Searching by moving trimmer